MARTIN MARIETTA DENVER DIVISION

APPLICATION OF REMOTE SENSOR DATA
TO
GEOLOGIC ANALYSIS OF THE BONANZA TEST SITE
COLORADO

SEMIANNUAL PROGRESS REPORT

1 October 1972 - 31 March 1973

Remote Sensing Report 73-2

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April 1973

REMOTE SENSING PROJECTS

DEPARTMENT OF GEOLOGY

COLORADO SCHOOL OF MINES ◆ GOLDEN, COLORADO

APPLICATION OF REMOTE SENSOR DATA

TO

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SEMIANNUAL PROGRESS REPORT

Compiled and Edited
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Semiannual Report, 1 October 1972 - 31 March 1973

INTRODUCTION

This report summarizes the research activities of the Colorado School of Mines faculty and students and the Martin Marietta Corp. scientists for the period 1 October 1972 to 31 March 1973. During this period, Professors Keenan Lee and D. H. Knepper, Research Associate D. L. Sawatzky, and graduate students R. W. Butler, R. J. Eichler, J. C. Fisher, and L. H. Jefferis of CSM, and research scientists R. C. Hulstrom, J. R. Muhm and K. E. Worman of MMC carried out research under the project.

ACQUISITION OF REMOTE SENSOR DATA

No aircraft support missions were requested during the report period. A flight request has been submitted to NASA/JSC for a P3 mission in June 1973.

PROGRESS REPORT ON GEOLOGIC REMOTE SENSING APPLICATIONS

Regional Geologic Mapping

Bonanza Test Site Geologic Compilation Map

A geologic map of the Bonanza Test Site is nearing completion. Using published large-scale geologic maps from various sources,the geology of the area is being compiled on a base scaled at 1:250,000.

Sources of previously published geologic mapping include: U.S.G.S. Bulletins, Professional Papers and Geologic Quadrangle Maps; Bureau of Mines Reports; Colorado School of Mines Quaterlies and Rocky Mountain Association of Geologist Guidebooks.

Published and unpublished C.S.M. and C.S.U. theses were also invaluable in the preparation of this compilation map. Thesis mapping includes a large portion of remote sensing data interpretations.

This compilation map will be used to evaluate ERTS, Skylab and remote sensing underflight data.

Detailed Geologic Mapping

General Statement

Research carried out during this period concerned the final analysis and evaluation of remote sensor data obtained from Missions 101, 168 and 184. Evaluation of the capabilities and limitations of the remote sensor data has been based on comparison with geologic field data collected during three summers' work. At present, the final report is in the process of being completed.

Review of Previous Work

Work previously completed on the project includes:

1) field mapping of the Buena Vista quadrangle, central Colorado.
2) acquisition and interpretation of NASA remote sensor data.
3) field checks of the accuracy of the interpretations carried out during step 2.
4) comparison of field and laboratory interpretations (steps 1 and 2).

Current Research

At present the final evaluations of the remote sensor data are being completed. In addition, a final geologic map has been constructed from all available data. The contribution to this map from remote sensor data is considerable, and represents a large saving in field time. Results of a rock discrimination study in an area where the bedrock is predominantly of Precambrian age have been especially significant in the

compilation of the geologic map. This rock discrimination work is discussed more fully below.

Rock Discrimination Study

Geologic Summary:

In the area of interest (approximately the SE 7½' quadrangle of the Buena Vista 15' quadrangle), five major units crop out. These include:

1) A Precambrian biotite gneiss, a remnant of the original country rock of the area.
2) A Precambrian quartz monzonite that intrudes the biotite gneiss.
3) A Precambrian leuco-granite that intrudes both the biotite gneiss and the quartz monzonite.
4) A series of Tertiary volcanic rocks that fill a NE-SW Paleovalley, and form a dome in the southern portion of the area.
5) Alluvial deposits of Quaternary age, which fill the bottom of the Arkansas Valley.

Rock colors for the Precambrian units provide the basis for discrimination on aerial photographs, and were thus studied in the field to determine the color differences. These colors are tabulated in Table 1.

Table 1

Precambrian Rock Colors from the Buena Vista Quadrangle*

Rock Unit	Color Description	Munsell Code
Leucogranite	moderate yellowish orange	10YR 5.5/4
Quartz Monzonite	grayish orange	10YR 6.5/4
Biotite gneiss	dark yellowish brown	10YR 4.5/3

*Colors measured on weathered surfaces using Geological Society of America Rock Color Chart.

Field and Laboratory Work:

Four figures are included to show the increased knowledge of the distribution of the various Precambrian rock units. These units presented a problem in field mapping because the contact was quite irregular, occasionally gradational, and the black and white prints used for mapping displayed little of the color difference that exists between the biotite gneiss and the intrusive units. In addition, little difference exists between the units in terms of topographic expression or texture on aerial photographs. Discrimination of these units was possible solely on the basis of color differences.

Figure 1 demonstrates the amount of information gathered from a few weeks of working in the southern portion of the study area. The contacts were drawn after a number of traverses of the area, and no attempt was made to walk out the contact between biotite gneiss and quartz monzonite. The contact was purposely generalized to separate areas of dominantly quartz monzonite from areas where biotite gneiss was dominant.

After obtaining and interpreting color photography from mission 168 it became evident that information about the contact was available which had not been evident on the black and white photos used in the beginning of the study. Re-examination of the high-altitude Mission 101 photography indicated the same type of information was available. Figure 2 indicates the results of the high-altitude (scale 1:110,000) color and color infrared photography interpretation and Figure 3 shows the results from interpreting the low-altitude

EXPLANATION FOR FIGURES 1 - 4

Quaternary Alluvium | Q

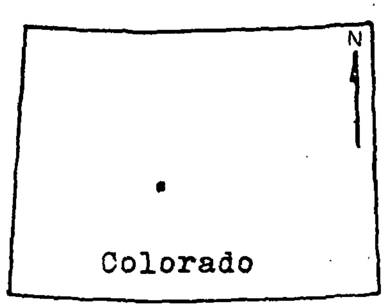
Tertiary Volcanics

Precambrian Leucogranite

Precambrian Quartz Monzonite

Precambrian Biotite Gneiss

Contact



Location of the Buena Vista SE Quadrangle

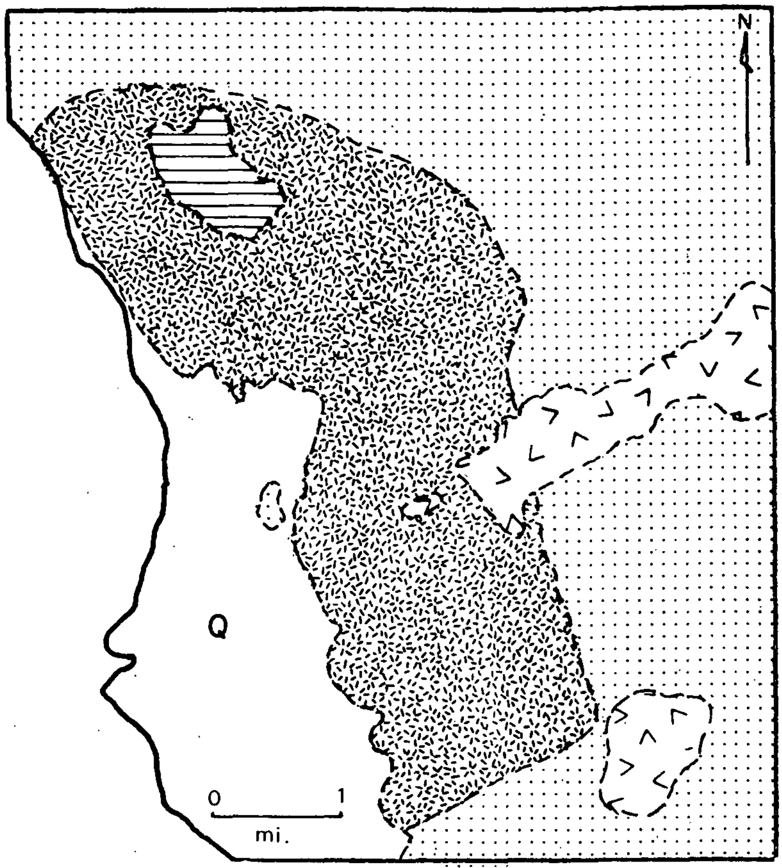


Figure 1. Interpretation after field work using 1:20,000 black and white aerial photos.

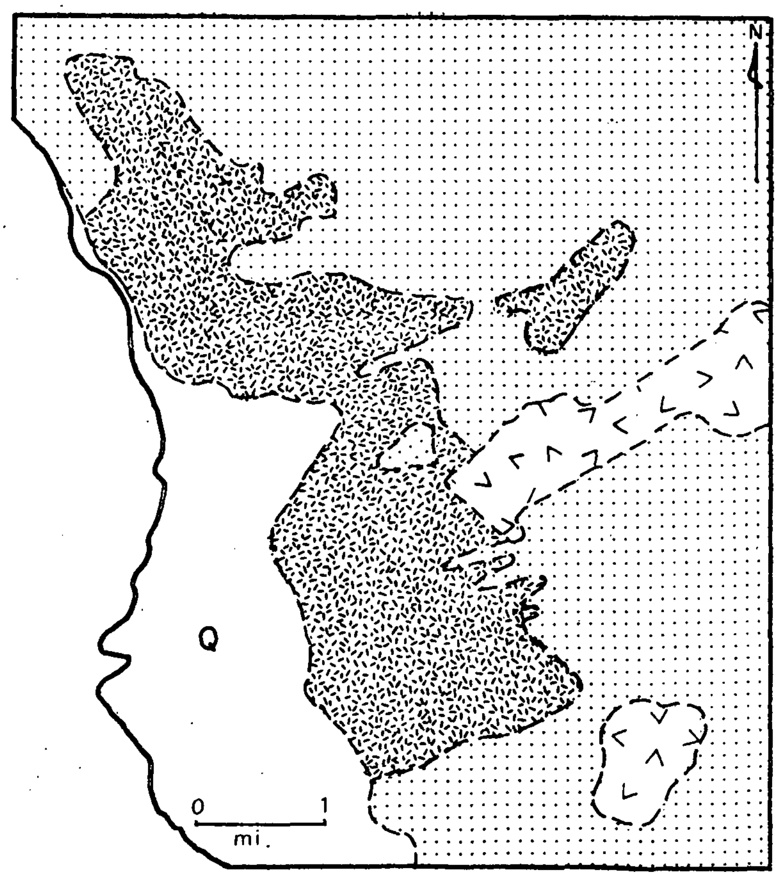


Figure 2. Interpretation using high-altitude (1:110,000) color and color infrared aerial photos.

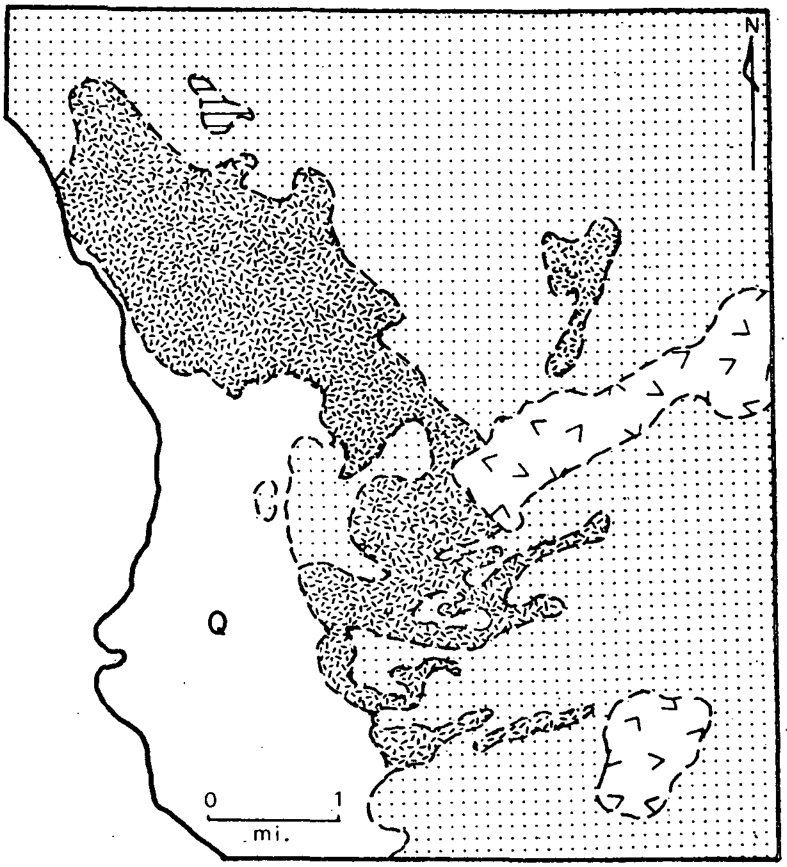
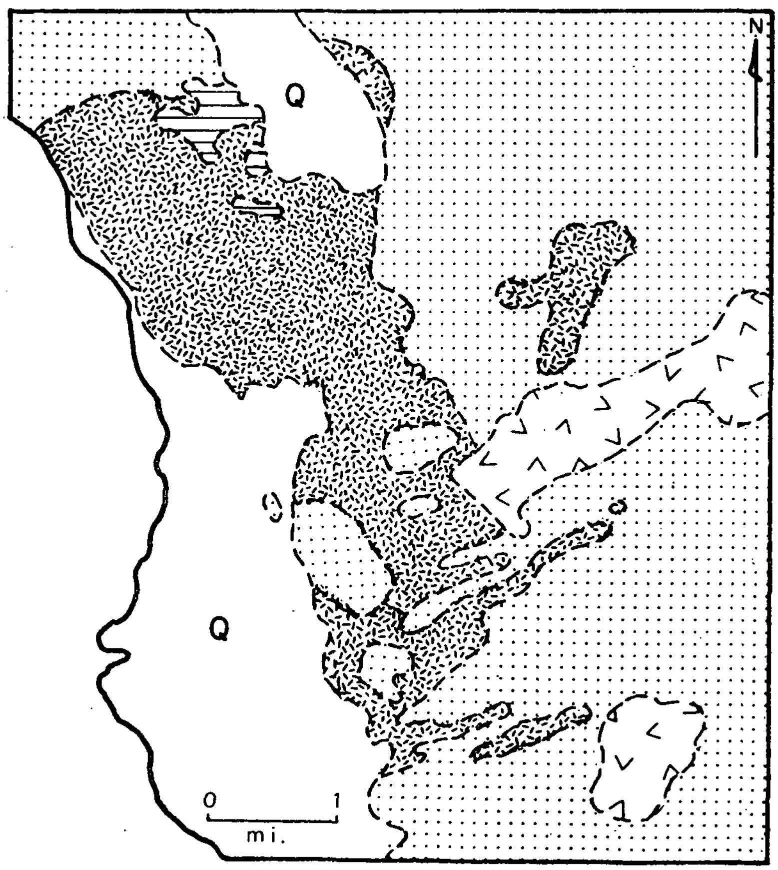


Figure 3. Interpretation using low-alitiude (1:20,000) color and color infrared aerial photos.

Figure 4. Final compilation map using all available data.



(scale 1:20,000) color and color infrared photos. It is evident that more information was available from the large-scale data; however, a considerable amount of easily extractable data was available from both types of photography.

Figure 4 was drawn after field checking the remote sensor data interpretations shown in Figures 2 and 3. All information available was used to construct Figure 4, and it was used to evaluate all previous interpretations.

Conclusions

Results of the study indicate the usefulness of color and color infrared photography for rock discrimination in areas where topographic expression and textural differences are not present between the rock units. In this study both large- and small-scale photography provided considerably more information than large-scale black and white panchromatic photos. The choice between large- and small-scale photos would have to be made on the basis of mapping scale.

Examination of thermal infrared imagery and SLAR imagery was also carried out for this portion of the study area, and yielded no usable information on the discrimination of the Precambrian rocks.

Surficial and Engineering Geology

Introduction

Research activities to date have consisted of the compilation of field and laboratory data to produce geologic, engineering geologic, hydrologic, and slope maps of the test site. Evaluation of the imagery over the test site obtained by Mission 205 was performed with respect to usefulness and potential applications to surficial mapping. In addition, research on the LSAP experiment (proposed in Remote Sensing Report 72-7) continued during the reporting period.

The test site is in the eastern portion of the Bonanza Test Site, approximately 3 miles north of Colorado Springs and immediately east of the U. S. Air Force Academy. The site covers 48 square miles in parts of Pikeview and Falcon NW 7½' quadrangles (Fig. 5).

Remote Sensing Evaluation

High-altitude color photography from Mission 205 was flown over the Colorado Springs area in June, 1972, and included RC-8 o-inch format color transparencies of approximately 1:105,000 scale and Hasselblad 70-mm format color transparencies of approximately 1:380,000 scale. Both camera systems were flown simultaneously, and the quality of the resulting photography was excellent, although slight attenuation by haze and light smog was encountered. The color photography was most useful in discerning minute tonal changes that were very difficult, if not impossible, to detect on the

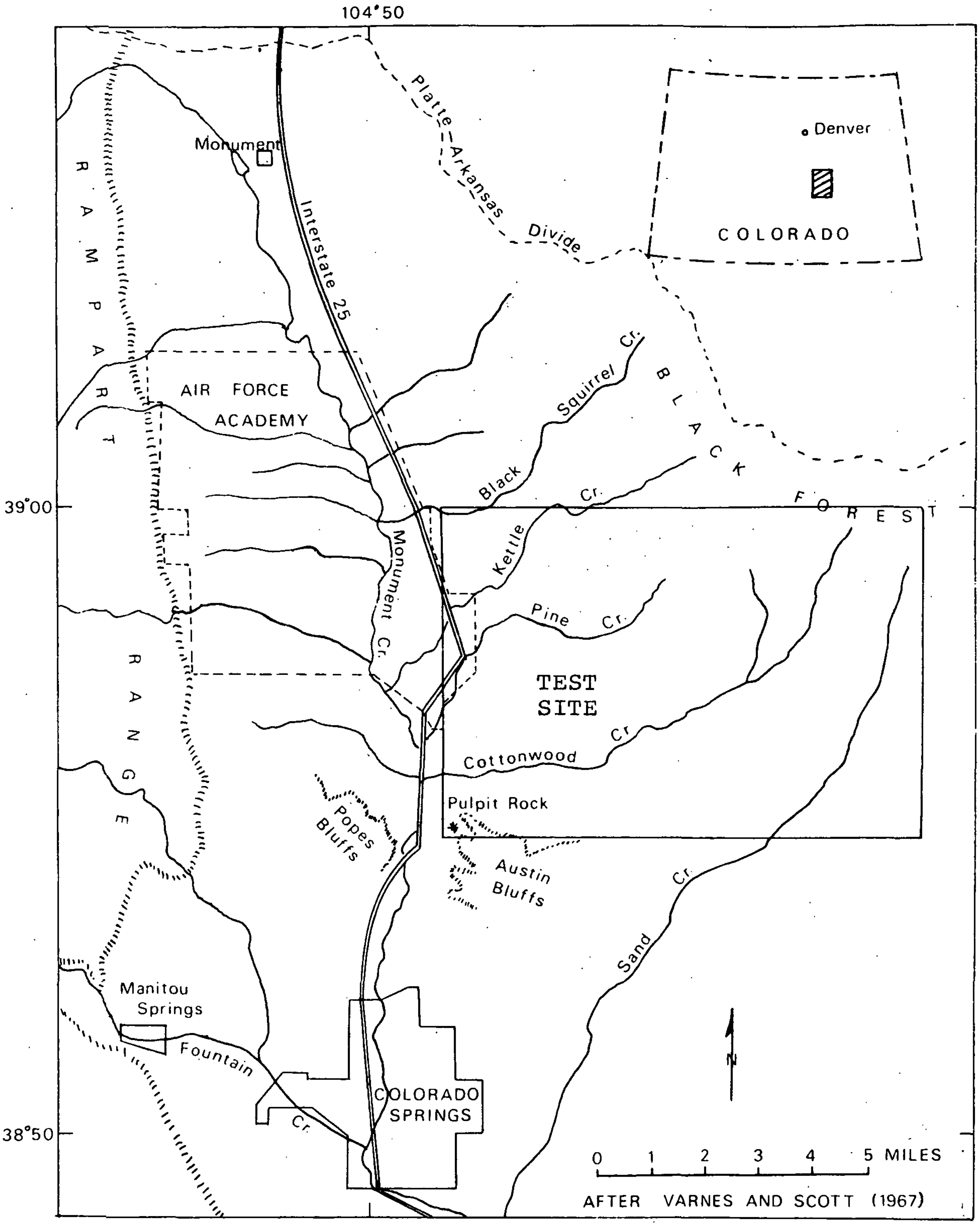


Figure 5. Index map of test site.

lower quality U. S. Geological Survey of U. S. Forest Service black and white photography at 1:20,000 scale. Discrimination of very low relief, windblown sand areas from the Dawson Formation and colluvium in the east part of the test site was facilitated using the color photography, particularly the larger scale RC-8 photography. Comparing maps generated from the color photography with a soil map compiled from U. S. Soil Conservation Service data, it is evident that color photography is very useful in maping major soil associations such as the Kettle-Pring-Peyton associations of the Stapleton-Columbine associations in the test site. Detailed soil unit discrimination should be possible using larger-scale (less than 1:48,000 scale) photography.

High-altitude color infrared photography, also from Mission 205 and flown simultaneously with the color photography, was also evaluated. In the test site, a small amount of additional information may be obtained by using high-altitude color infrared rather than high-altitude color photography. Areas of high sand content, such as in the west central part of the test site, may be more easily delineated because the sand has a higher reflectance in the infrared than the underlying Dawson Formation. Discrimination between the sandstones and shales of the Dawson Formation and the overlying windblown sand deposits is very tenuous at this scale in areas where the sand is not present in a distinctive topographic character, such as a dune form, but instead forms a veneer over the Dawson. This sand veneer, as observed in the field, is generally less

than 3 feet thick. Discrimination of the windblown sand deposits from the Dawson Formation, in areas where distinctive topographic form is absent, is further complicated by the fact that the Dawson Formation is often unconsolidated and assumes the same texture on a photograph as the sand deposits. Since the windblown sand deposits in the test site were derived primarily from the Dawson Formation, these two map units are very similar in color and lithology. Accurate discrimination of these units, then, cannot always be made without field investigations. The lack of physical diversity between the Dawson Formation, windblown sand, pediment gravels, and terrace alluviums, generally inhibits photo mapping in the test site unless the distinctive topographic forms of these respective units are present. Enhancement of these low-relief topographic forms was not found to be adequate with this small-scale stereo photography.

Due to the unusually high amount of snowfall in the test site from November, 1972 through March, 1973, the LSAP experiment proposed for the test site in RSR 72-7 was delayed to late April or early May, 1973. During this past report period, simulated LSAP studies were performed in the laboratory using plastic relief maps of the Colorado Springs area at 1:250,000 scale. These studies indicate that the illumination angle necessary for optimum enhancement of the sand dunes in the test site is about 10 to 15 degrees, and the optimum illumination azimuth appears to be from the west, such that shadows are cast across the east-facing slip faces of the parabolic dunes.

Plans

The LSAP mission proposed in RSR 72-7 will be flown in late April or early May, 1973. The first phase of this project will be to fly a test strip over the test site to evaluate photographic parameters in order to obtain the best quality photography during the LSAP mission. The second phase will include execution of the proposed LSAP mission in early May. The third, or interpretive, phase of the project will be conducted during the summer.

Fracture Studies

Introduction

Investigation continued on evaluation of the recognition and mapping of faults and regional fracture patterns from linear features on photographs and scanner imagery. Emphasis in this phase was on developing a method for producing computer-compatible data, modifying existing computer programs, and making the first computer-assisted analyses of the linears.

Data Collection

All linear features on a positive image are traced onto a clear overlay. On high-altitude or orbital imagery, the objectivity of tracing all inears is more justifiable than on low-altitude imagery where cultural features such as landlines constitute a large part of the data. However, in the final analysis, trends due to these sources can be easily interpreted and discarded if desirable.

Azimuths of the linears and segments of curvilinears are measured with an azimuth-indexed turntable. Data are recorded for 16 equal areas of the image on data forms compatible with computer card format.

Computer Program

The computer program accepts azimuths for input and produces printer lists and plots for analysis. The first plot is an absolute strike-frequency graph on 1-degree intervals (Fig. 6). The range of the graph is 180 degrees from N.90W. to N.90E.

ABSOLUTE STRIKE FREQUENCY ANALYSIS.

ERTS LINEARS 24DEC 72

10 LEVELS OF FREQUENCY AT 1 PER LEVEL.

NO. OF DATA = 421

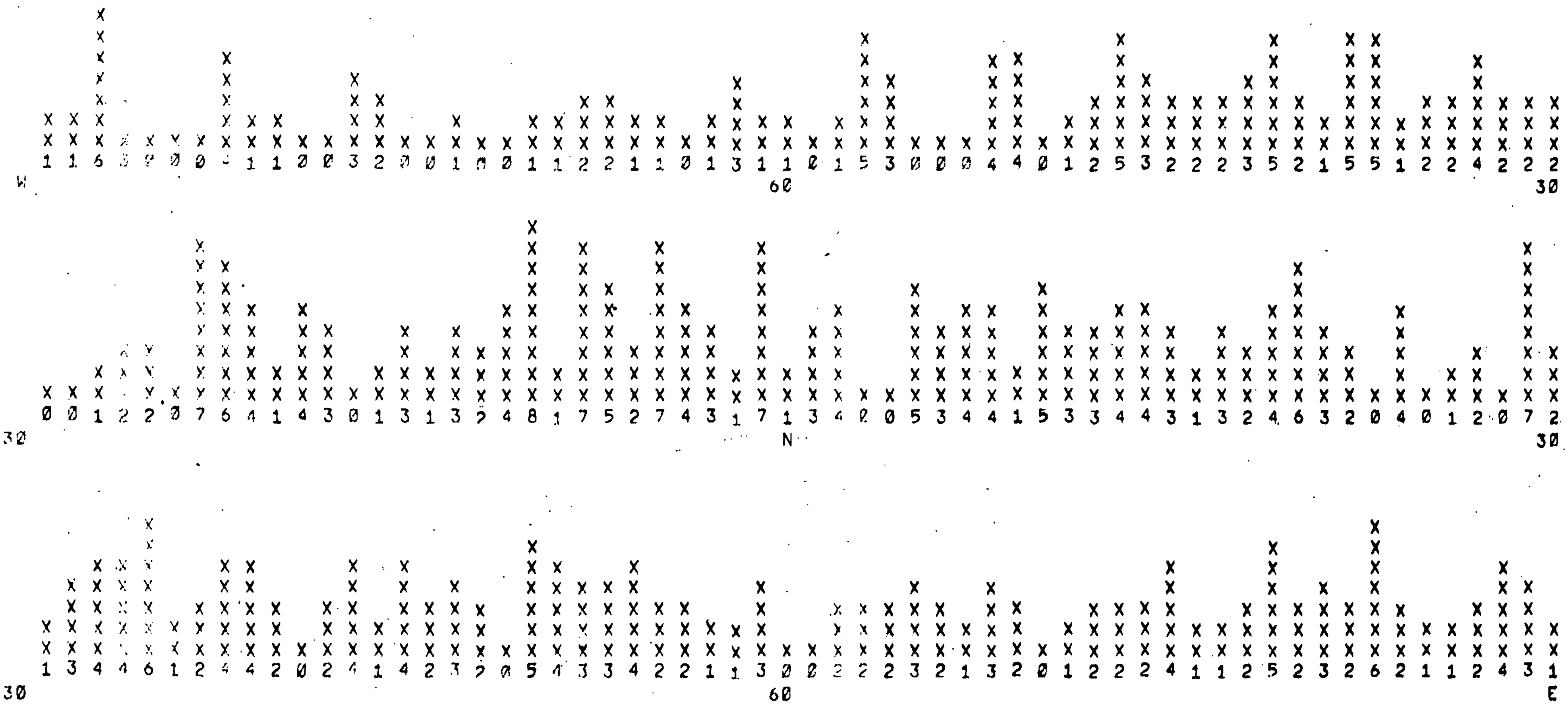


Figure 6. An example of a printer plot of an absolute strike-frequency graph.

The second plot is an empirical frequency graph similar to the first (Fig. 7). It is constructed by smoothing the absolute frequency data over a 3 percent interval of the 180-degree range. This graph is used in the statistical significance test.

The two plots are followed by two tables. The first (Fig. 8) is a table of significance levels for the values of empirical frequency. The significance levels are calculated from the binomial distribution, the number of azimuths, and the smoothing factor. In general, levels gerater than 0.5 are significant and values above 0.9 are very significant.

The last table (Fig. 9) contains azimuths and values of the maxima in the empirical frequency data.

Computer-assisted Analysis

The azimuths of the maxima of maxima in the table are the main trends of the linears (Fig. 9). Maxima frequencies, and therefore their significance values, are interdependent; that is, large numbers of one trend can conceal trends of small number. This is acceptable so long as the trends are all of the same origin. It may be desirable to recognize and discard data of landlines or roads and reanalyze the remainder.

Preliminary Results

The method was applied to an ERTS MSS image of a part of the Bonanza test-site. Less than 5 percent of the linears could be directly attributed to cultural features. A few percent are due to structures in sedimentary rocks and most

EMPIRICAL STRIKE FREQUENCY ANALYSIS.

ERTS LINEARS 24DEC 72

10 LEVELS OF FREQUENCY AT 3 PER LEVEL.

PERCENT AZIMUTH FOR SMOOTHING = .03

NO. OF DATA = 421

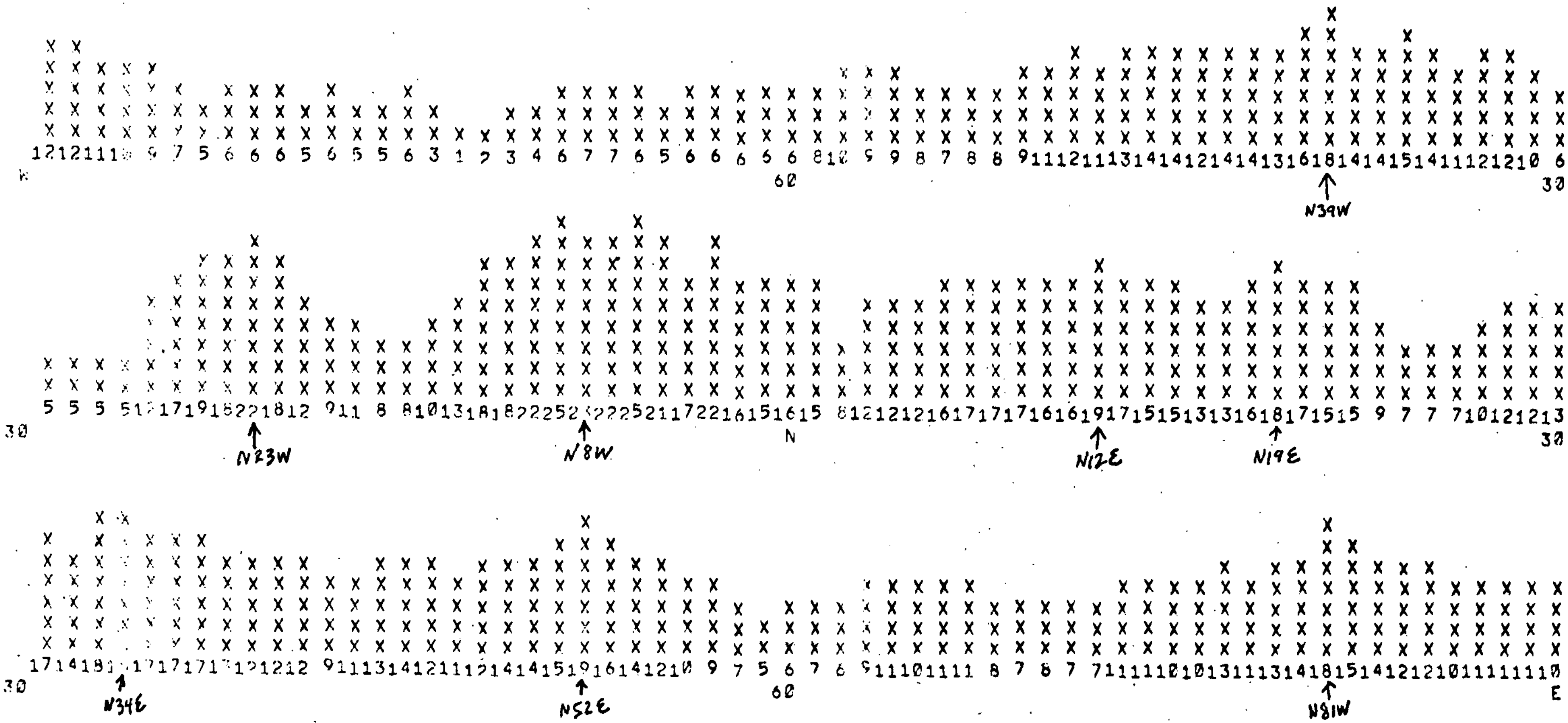


Figure 7. An example of a printer plot of an empirical strike-frequency graph. Significant trends, determined by the method explained in the text, have been annotated.

ERTS LINEARS 24DEC 72

FREQUENCY PROBABILITY DATA

NO. OF DATA = 421 EVENT PROB. = Ø.Ø3Ø PROB. LIMIT = Ø.999

FREQUENCY MEAN = 12.6

ABS. FREQ.	REL. FREQ.	FREQ. PROB.	ONE-WAY PROB.
4	1.5	.ØØ3	.991
5	1.7	.ØØ8	.975
6	1.9	.Ø18	.94Ø
7	2.2	.Ø32	.876
8	2.4	.Ø52	.773
9	2.6	.Ø73	.627
1Ø	2.9	.Ø93	.441
11	3.1	.1Ø8	.227
12	3.4	.114	.ØØ2
13	3.6	.111	.ØØØ
14	3.8	.1ØØ	.224
15	4.1	.Ø84	.425
16	4.3	.Ø66	.594
17	4.5	.Ø49	.727
18	4.8	.Ø34	.825
19	5.Ø	.Ø22	.893
2Ø	5.3	.Ø14	.937
21	5.5	.ØØ8	.965
22	5.7	.ØØ5	.981
23	6.Ø	.ØØ2	.99Ø
24	6.2	.ØØ1	.995

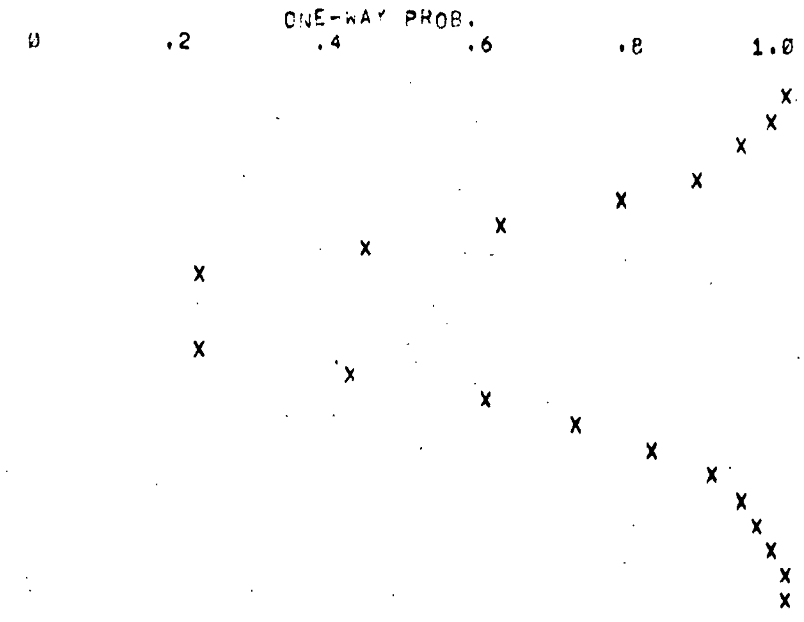


Figure 8. An example of a printer list of a significance value table.

LOCATION OF MAXIMA AND THEIR ONE-WAY PROBABILITIES.

AZIMUTH	EMP. FREQ.	PROB.
314	14	.224
318	14	.224
32[illegible]	18	.825 *
324	15	.425
337	19	.893 *
339	22	.981
351	25	.998 *
354	25	.998
357	22	.981
[illegible]	16	.594
6	17	.727
12	19	.893 *
19	18	.825 *
3[illegible]	17	.727
34	18	.825 *
45	14	.224
5[illegible]	19	.893 *
7	13	.[illegible]
[illegible]	18	.825 *

Figure 9. An example of a printer list of a table of empirical frequency maxima.
* Denotes maxima of the maxima.

are from igneous and metamorphic terrains. Eight significant trends were found, and they are parallel to known regional structural trends. The trends are strongly area-dependent, each being found in usually less than half of the 16 subdivisions of the imaged area.

Plans

A number of modifications and applications will be made to the method of analysis. The computer program will be modified to accept the lengths of linears as weighting factors of the frequencies. This will increase the significance of long, isolated linears with respect to short, closely spaced ones.

Applications will be made to imagery at larger scales and to geologic data. Through autocorrelation of empirical frequency graphs of the imagery and the geologic maps of an area, an evaluation of geofracture mapping from imagery will be made.

Fracture Enhancement Studies

Introduction

The last semi-annual progress report (Remote Sensing Report 72-7) described the sharp-mask technique of photo-lineament enhancement that is currently under investigation. Research during the past six months has concentrated on quantifying the effect of such enhancement. Some preliminary results are described in the following sections.

Aerial Photograph Enhancement

Figure 10 in an air photo taken from the NASA B-57 during August 1969 on NASA Mission 101. The photo is oriented such that shadows fall toward the observer for convenience in visualizing the topography, and north is arbitrarily shown to the top. Figure 11 shows the same photo, printed with a translationally-slipped sharp mask.

Photo-lineament interpretations were made on the above two photos by annotating clear plastic overlays. The resulting interpreted photo-lineaments were then measured, both by azimuth (strike direction) and by length. Data were grouped into 10° increments, and tabulations were made of both the number of photo-lineaments per 10° increment and the total length of lineaments per 10° increment. These data are shown in Figure 12, where only the northern hemisphere is shown. Inspection of Figure 12a clearly indicates that the masked photo provides <u>more</u> information - that is, a greater number of photo-lineaments. The actual number of lineaments from the

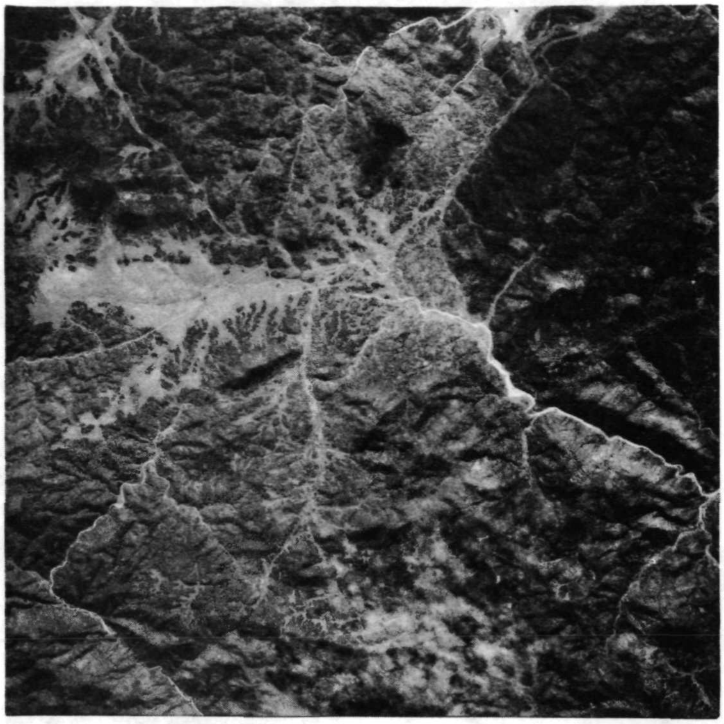


Figure 10. Aerial photograph, Mission 101, Hasselblad, scale - 1:120,000.

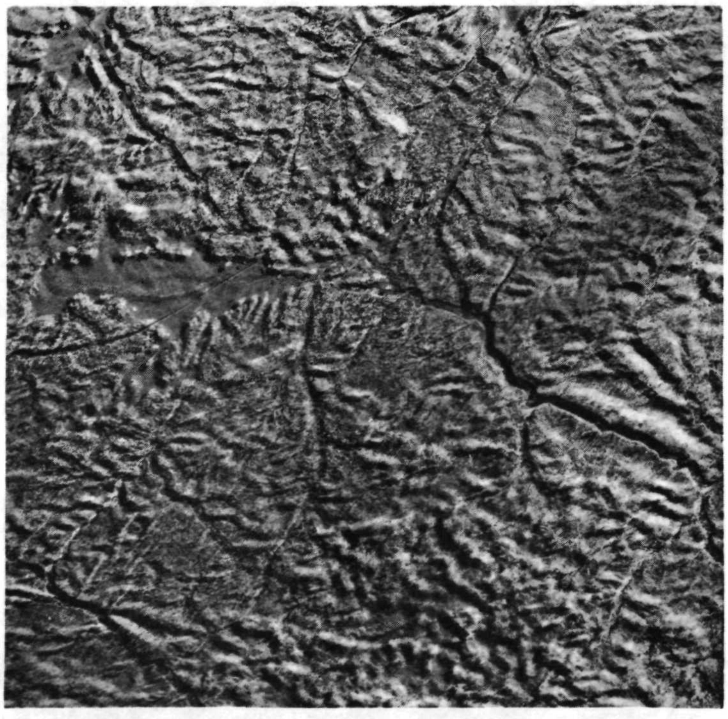
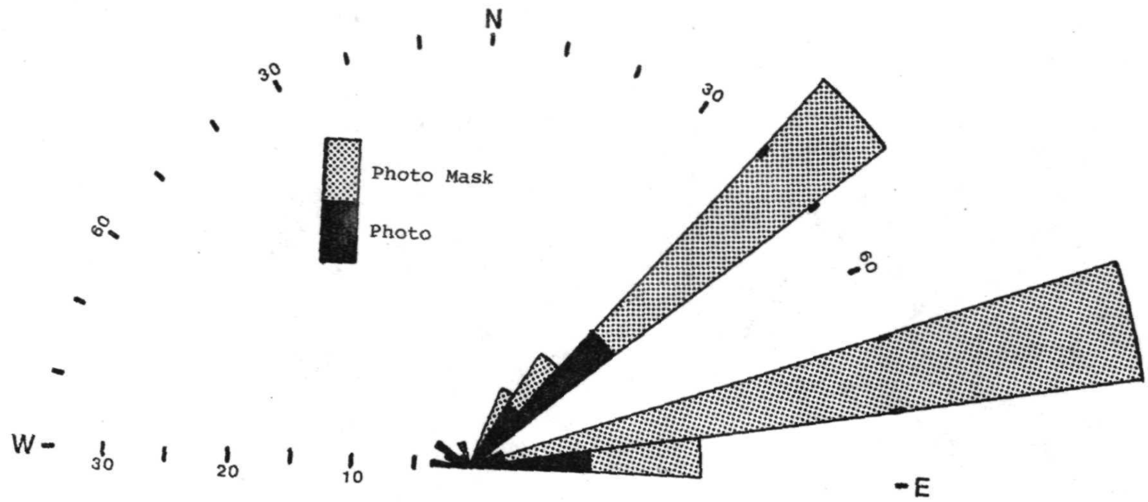
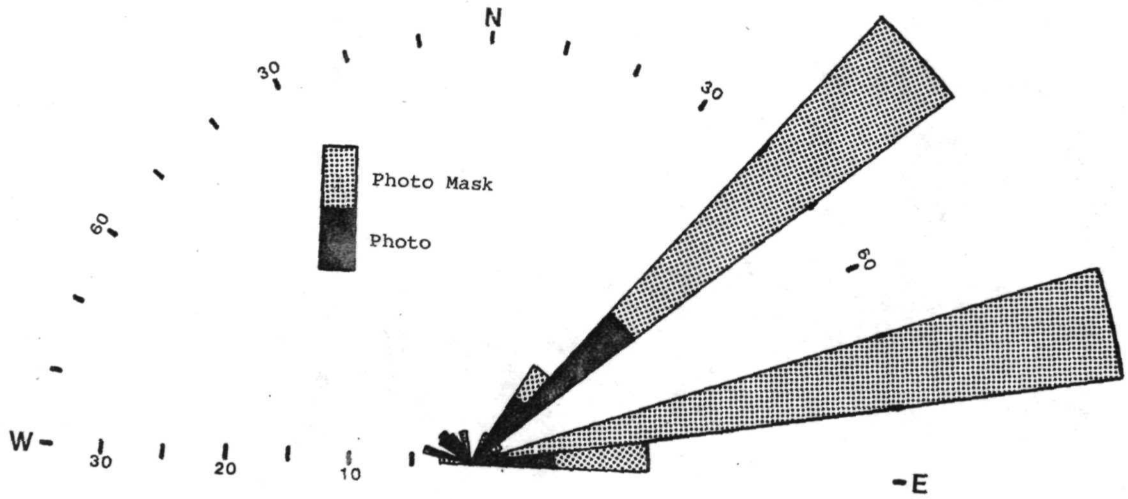


Figure 11. Masked print of aerial photo shown above.



a. Distribution based on numbers of photo-lineaments.



b. Distribution based on cumulative lengths of photo-lineaments.

Figure 12. Photo-lineaments interpreted from aerial photo and from masked aerial photo.

photo was 48, while the masked photo yielded 149, a three-fold increase.

To investigate the question of whether one or the other of the photos is providing more significant information in terms of major lineaments, each of the lineaments was weighted by its length. This was done simply by adding the accumulative length of lineaments (in arbitrary units) in each 10° segment. Figure 12b shows these data, and comparison of Figures 12a and 12b shows that there is no significant difference.

From the discussion thus far, it is clear that the photomask provides more photo-lineament information. Inspection of either of the above two figures also suggests that the <u>kind</u> of information is also the same - that is, more of the same kinds of lineaments are being detected. To quantify this relationship, a linear correlation coefficient analysis was performed, correlating the photo-lineaments from the photo with the photo-lineaments from the photo mask, as a function of azimuth. The auto correlation coefficient, based on numbers of lineaments, was 0.63; the coefficient based on lengths of lineaments was 0.68. These results indicate a statistically significant correlation between the kinds of information derived from the two different analyses. As a check on the statistical significance of these results, the data from both analyses were purposely miscorrelated by 10°, both to the east and west, and the resulting autocorrelation coefficients dropped to 0.15 and - 0.18.

SLAR Imagery Enhancement

An analysis was made on SLAR imagery and masked SLAR imagery, similar to the photo study described above. The results were also similar; 14 lineaments were interpreted on the SLAR imagery and 60 on the masked imagery. Autocorrelation coefficients were 0.56 (number of lineaments) and 0.54 (cumulative lengths of lineaments).

Relief Model Enhancement

In both of the above studies, an increase in information content was achieved by translational offset of the negative-positive mask, in one direction only. To investigate the possible further increase in information from translating (slipping) the mask in more than one direction, a series of eight masks were made with slip differences of 45°. The original photograph used was a photograph of a plastic raised relief model (see below), photographed using low-angle illumination. The original is shown in Figure 13 and one of the eight masks is shown in Figure 14. The original photo provided 83 lineaments; each of the eight masks yielded numbers ranging from 49 to 101. When the photo-lineaments from the eight masks were compiled, and duplicate data eliminated, the total number of lineaments was 200. Figure 15 shows these results.

Simulated Low Sun-Angle Photography

Following the initial work of D. Wise and other researchers (Wise, 1969; Hackman, 1967), studies were conducted with plastic

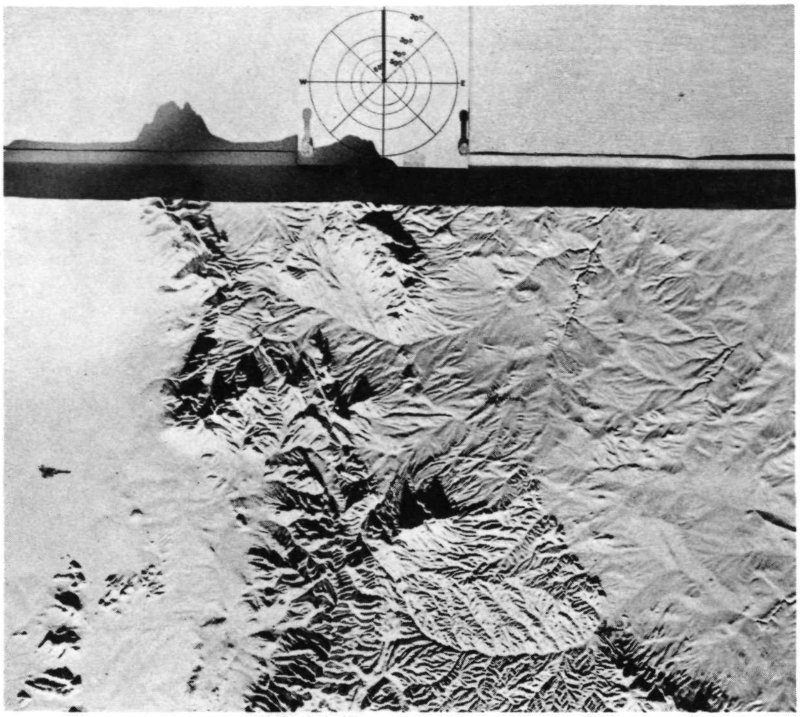


Figure 13. Simulated LSAP using plastic relief model.

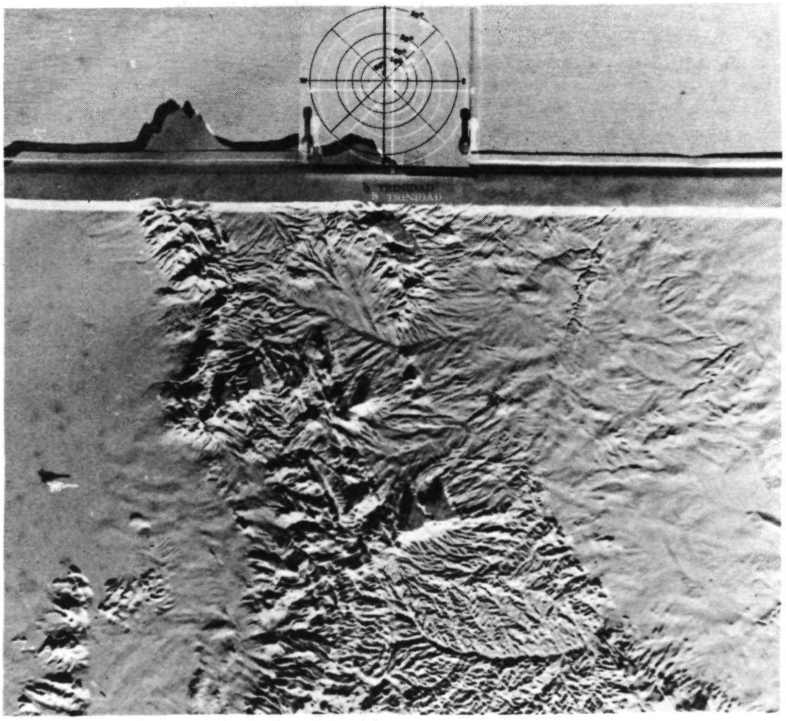
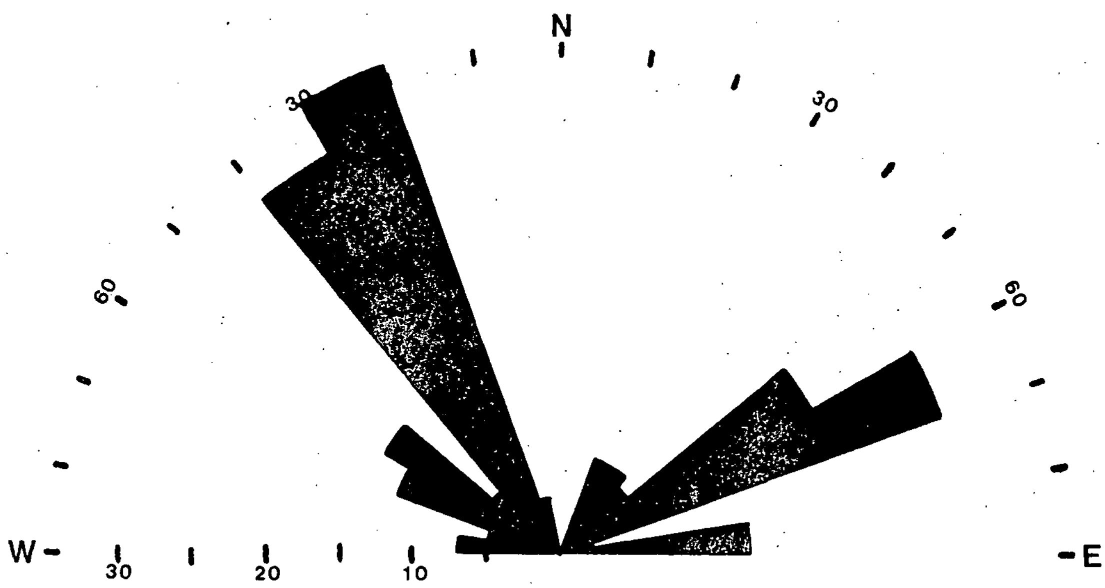


Figure 14. Masked print of simulated LSAP shown above.

a. Photo-lineaments from simulated LSAP.



b. Photo-lineaments from masked simulated LSAP.

Figure 15. Photo-lineaments interpreted from simulated LSAP and from masked simulated LSAP.

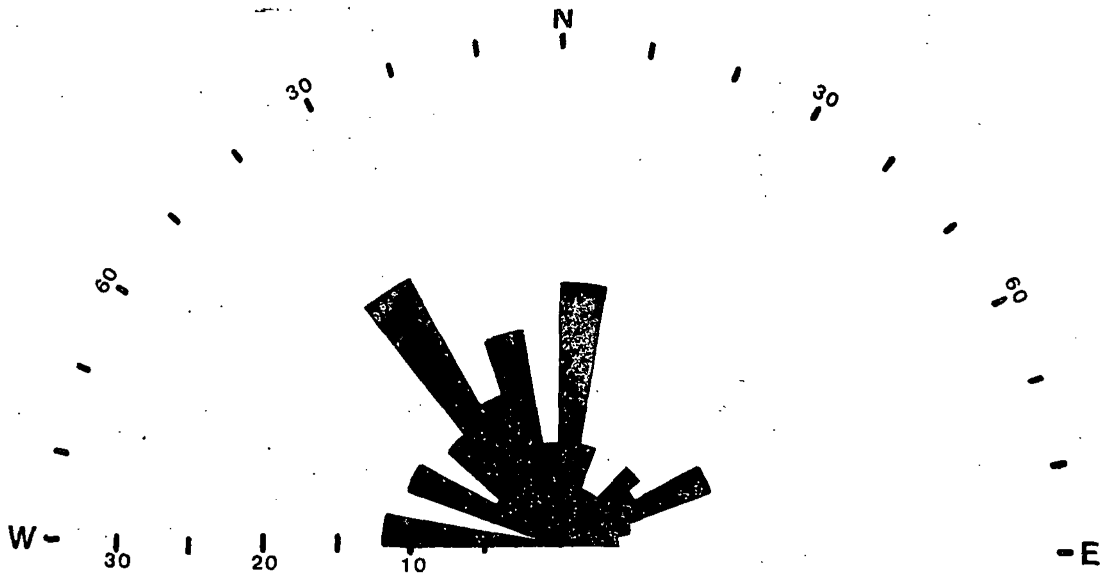
raised relief models to simulate low sun-angle photography (LSAP). The plastic models were originally made by the Army Map Service at a scale of 1:250,000, and are available for most of Colorado. These models were spray painted with a flat white paint to cover over all printed information, with the result that only topography remained. Most work to date has been done with the Trinidad quadrangle, because it is the only quad, entirely within Colorado, that has a published geologic map at the same scale.

Simulated LSAP shows a high correlation between the azimuths of photo-lineaments detected and the illumination azimuth, as was expected. Because of this phenomenon, simulated LSAP was taken at eight different illumination azimuths (N, NE, E, etc.) at a constant illumination angle (20^{o}). Lineaments were interpreted on the individual photos, and then a composite map of the quad was made.

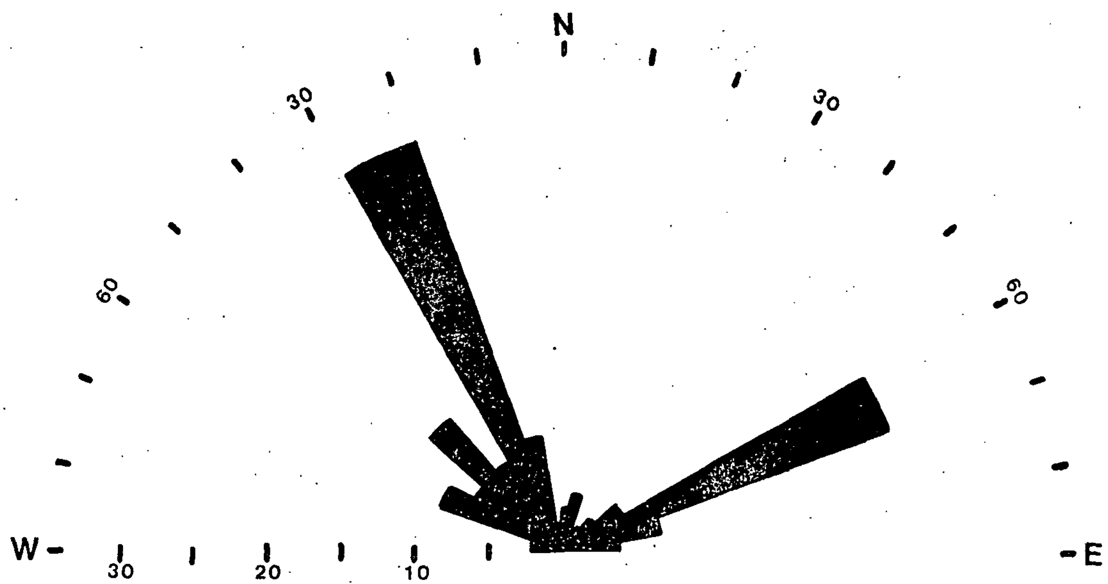
Comparison of the compiled simulated LSAP results with the geologic map yielded the following results. The total number of faults mapped in the quad was 163. The total number of photo-lineaments interpreted was 132. Of these totals, 50 lineaments were common to both - that is, 50 of the mapped faults were detected by the simulated LSAP.

A comparison of the trends of these two sets of lineaments is shown in Figure 16. The autocorrelation coefficients for these data were 0.34 (numbers) and 0.27 (length).

The significance of the differences in these data remains to be explained. In a qualitative sense, the following observations are pertinent. Of the 163 mapped faults on the geologic



a. Faults mapped on geologic map.



b. Photo-lineaments from compilation of simulated LSAP at eight different illumination directions.

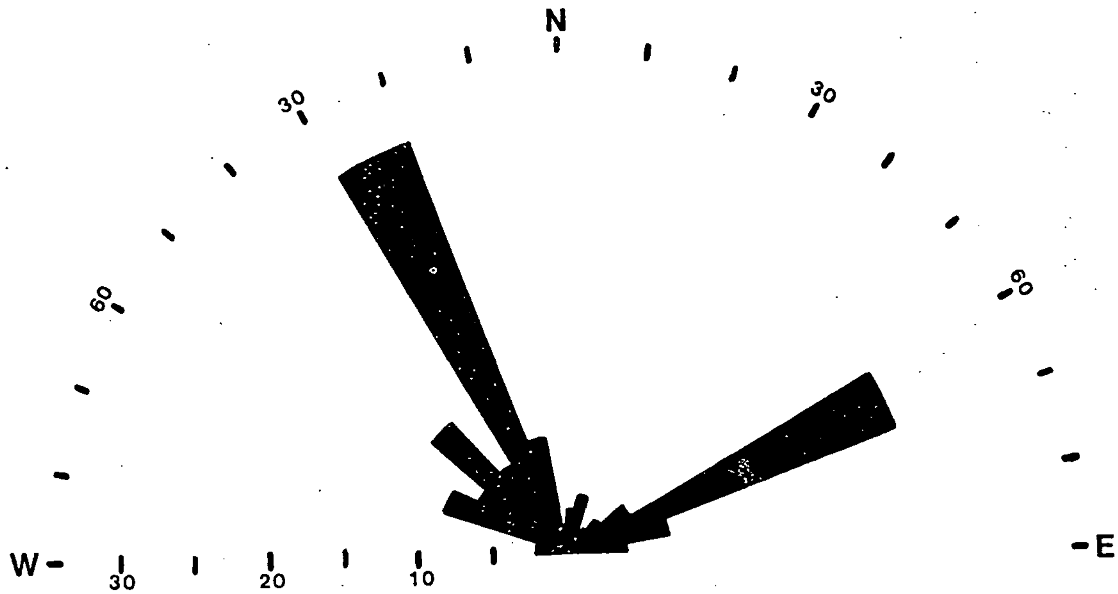
Figure 16. Comparison of photo-lineaments from simulated LSAP with mapped faults.

map, all of the major faults were detected on the LSAP. In many cases the LSAP analysis showed extensions of known faults, beyond what the geologic map showed. Many of the mapped faults were simply too small for the scale of the LSAP model. Several of the faults were not picked on the LSAP because they were coincident with hogbacks - that is, they were strike faults. Several of the photo-lineaments turned out to be dikes (the Spanish Peaks and related dike systems). Several of the lineaments seen on the LSAP, and not on the geologic map, are in relatively flat-lying Paleocene-Eocene sediments, and were they faults, would be very difficult to map in the field.

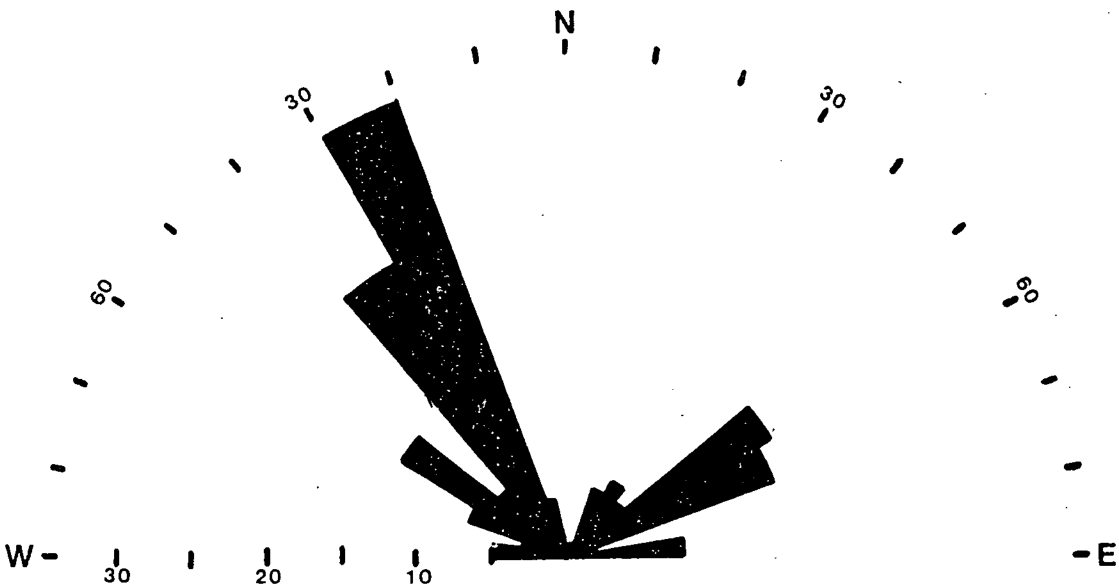
It was noted in the last progress report (RSR 72-7, p. 23) that the results of masking one simulated LSAP photo in eight different mask directions produced comparable results to eight separate LSAP illuminations. These results have now been quantified, and are shown in Figure 17. The total number of photo-lineaments from the compiled LSAP, as stated above, was 132. The multiple masking of one of these LSAP photos (south illumination, 20^{o} angle) provided 152 photo-lineaments. The autocorrelation coefficients for these data are 0.70 (numbers) and 0.70 (length), showing a highly significant correlation.

Plans

Research will continue on these fracture enhancement studies during the current six-month period. Emphasis will continue to be placed on the quantification of results. Questions to be further investigated are: the effect of illumination direction, the effect of masking direction, and most important, of course, the significance of the photo-lineament information in terms of geologic phenomena.



a. Photo-lineaments from compilation of simulated LSAP at eight different illumination directions.



b. Photo-lineaments from compilation of masked simulated LSAP at eight different masking directions.

Figure 17. Comparison of photo-lineaments from eight different LSAPs vs. eight different masks of one LSAP.

Mineral Deposits Exploration

Introduction

An evaluation of the relative utility of various remote sensing tools as an aid to mineral exploration will be undertaken in an area of known uranium and minor base metal mineralization.

The area chosen for this evaluation is the Ralson Buttes area, Jefferson County, Colorado. This area is a Precambrian terrain of meta-sediments and meta-volcanics intruded by quartz monzonites and granodiorites. Laramide faulting and brecciation controlling the localization of most of the uranium mineralization are important geologic factors.

Remote Sensing Evaluation

The following remote sensors will be evaluated for their utility in mineral exploration:

1. High and low altitude color photography - The photography will be used for basic geologic mapping. Since the mineralization of the Ralson Buttes area is in faulted hornblende-garnet-biotite gneisses, it is hoped that color photography can be used to map these units and localize potential areas of possible pitchblende concentrations.

2. High and low altitude color IR photography - This will also be used in basic geologic mapping. Mineral effects on vegetation may also be seen on color IR photography.

3. Multiband photography with color additive viewing - These data should aid in a more detailed geologic mapping program.

False color additive viewing shows great promise in delineating pegmatitic intrusives and meta-sediment schistosity.

4. Thermal IR imagery - Thermal imagery will be an aid to basic rock unit mapping and location of the important faulting that controls mineralization.

5. Infrared Spectrometry - This will also be an aid to lithologic mapping. Rock units with sufficiently different spectra can be delineated and mapped.

6. SLAR imagery - These data may help in the location of faulting and brecciation in the Ralston Buttes district. Uranium mineralization seems to be located in complexly sheared and fractured gneisses, and it is hoped that SLAR imagery will locate these areas. SLAR imagery will be requested on future NASA aircraft missions only if the DPD-2 SLAR system is replaced by a worthwhile instrument.

7. LSAP photography - This will be used in essentially the same way as the above SLAR imagery. If NASA cannot provide usable SLAR imagery, LSAP alone will be used.

8. Other techniques - Various geochemical and geophysical methods of remote sensing will also be evaluated. Such techniques as ground and airborne scintillometer spectrometry, radon soil gas emanometry, sulfur gas emanometry, aeromagnetic surveying, and rock/soil/sediment geochemical sampling will also be investigated.

Results

It is hoped that a successful application of remote sensing

data to mineral deposits exploration will promote a wider-spread utilization of these techniques throughout industry and science.

Plans

Ground studies will be conducted in the Ralston Buttes area this summer. A NASA mission has been requested for June, with the P3A, to acquire data over the test site.

Hydrogeology

Introduction

Two test sites have been chosen to evaluate selected remote sensors for usefulness in hydrogeologic investigations. The primary objective of the tests is the detection of subsurface and near-surface water. Ground studies at the test site areas, including geologic mapping, sampling, and laboratory investigations, will be conducted during the summer and fall of 1973.

Test Sites

The test sites are in the western part of Park County, Colorado, and are part of the intermontane basin, South Park (Fig. 18).

Test site #1 is a 50 square mile area on the east slope of the Mosquito Range. The test site is a drainage basin defined by the headwaters of the Middle Fork of the South Platte River. Topographic relief is approximately 4,000 feet, with elevations ranging from 10,000 feet in the southeastern part of the area to over 14,000 feet in the west. Much of the area has been heavily glaciated. Vegetation consists of associations of woodlands and grasslands of sub-alpine areas (spruce, fir, pine, aspen, and fescue grasses) and grasslands and meadows of alpine regions above timberline (sedges, grasses, willow, birch, and forbs) (Soil Conservation Service, 1972).

Previous geologic studies in the area have dealt mainly with ore deposits and mineralization. Geologic units include

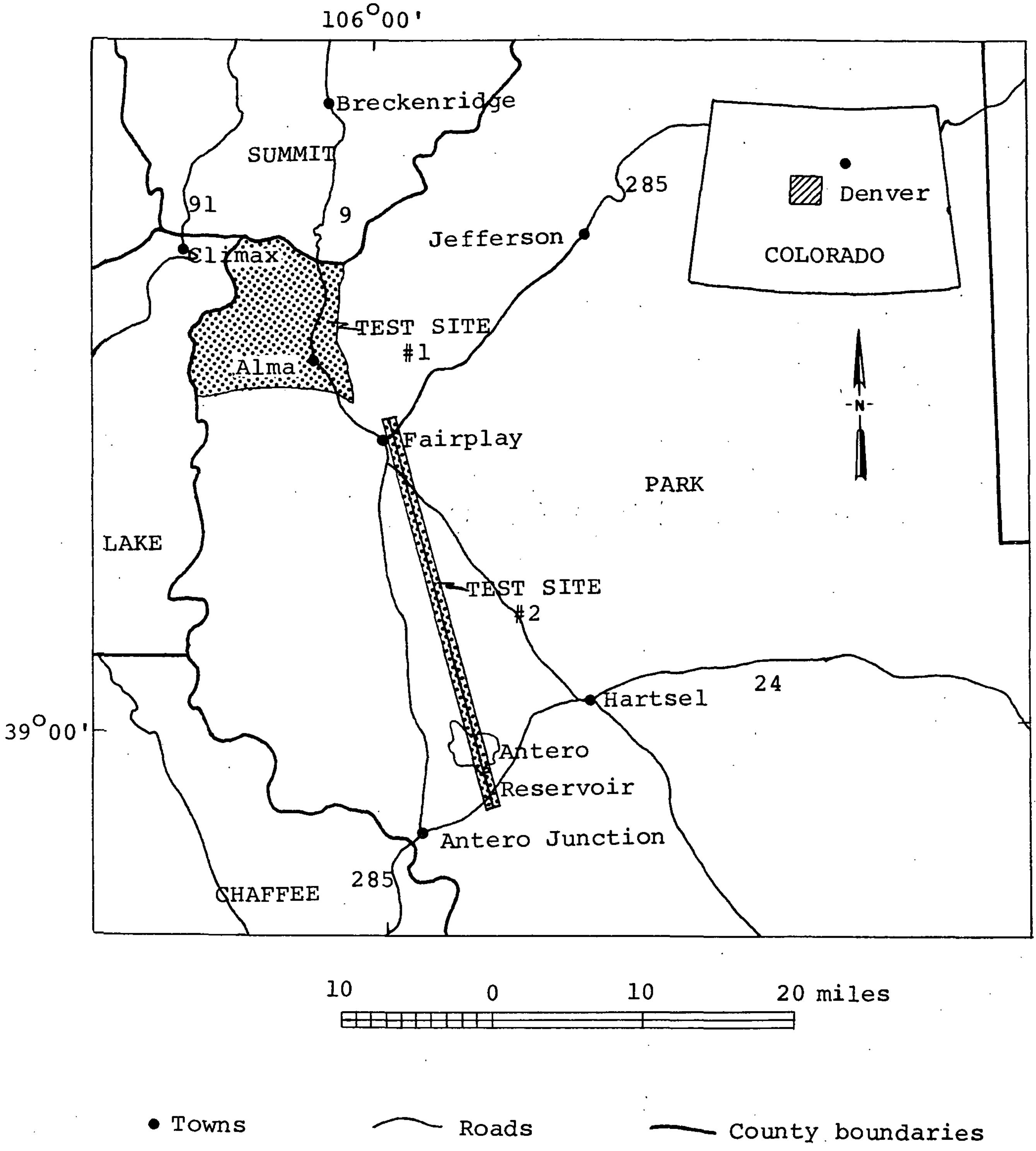


Figure 18. Index map of the remote sensing test areas for hydrogeology.

Precambrian igneous and metamorphic rocks, Paleozoic sedimentary rocks, Tertiary and Upper Cretaceous intrusive rocks, and Quaternary alluvial and glacial deposits (Tweto and Case, 1972). The availability of ground water is variable, depending upon the lithology.

Test site #2 is a 20 mile long strip from Antero Reservoir to Fairplay. Topographic relief is approximately 1,000 feet, with elevation increasing from about 9,000 feet in the south to 10,000 feet in the north. Vegetation consists of high mountain park and valley grasslands (grasses, scattered pinyon and juniper, sagebrush, and rabbitbrush) (Soil Conservation Service, 1972).

The geology of the test site is Pleistocene terrace gravels and glacial deposits. These surficial deposits can be subdivided into a pre-Illinoian terrace gravel, pre-Wisconsinian (Illinoian?) glacial deposits and Wisconsinian terrace gravels and till. The unconsolidated Quaternary sediments are the most productive aquifers of South Park (U.S.G.S., 1964).

Objectives

The primary objective of this study is the evaluation of selected remote sensors for their ability to detect subsurface and near-surface water. The study has been divided into two test sites because of differences in methodology and types of remote sensors being evaluated.

Test site #1 coincides with a current Master of Science thesis in hydrogeology. Extensive ground studies will be

conducted to determine the lithologic and structural controls of ground water. This area will be the test site for high- and low-altitude color and color infrared photography. The photography will be used to aid in general geologic mapping and for the detection of vegetation anomalies that are controlled by ground water - for example, phreatophytes growing along faults and fractures. Other uses of the photography are anticipated as field work proceeds.

Test site #2 will be used for an evaluation of nighttime thermal infrared and passive microwave imaging systems for detecting ground water and soil moisture. Soil moisture is one of several parameters that directly affects the emission of microwave and thermal infrared radiation by changing the dielectric properties of the material (microwave region) and the thermal diffusivity (thermal infrared region). The Antero Reservoir-Fairplay test site was chosen because it represents a fairly homogeneous area in terms of geology, topography, and vegetation.

The microwave-thermal infrared test site will be covered by a single flight line. The 70° field of view of the microwave imaging system will result in a strip approximately 4800 feet wide at an altitude of 3500 feet amt. Information derived from one type of imagery will be correlated with the other, as well as with low-altitude color and color infrared photography and ground studies.

Data Reduction and Enhancement

Introduction

Research during the report period centered on two main areas of data handling - electronic enhancement of scanner imagery and computer-reduction of IR spectrometer data. Photogeologic interpretation and field checks were conducted in support of these tasks.

Electronic Enhancement of Scanner Imagery Data in Analog Form

During the report period, a task was initiated to investigate methods to improve upon the data content and interpretability of thermal and multispectral scanner imagery. Much of the background of this task is discussed in RSR 72-4.

An additional item of capital equipment, received in October 1972, now provides a means to produce continuous strip imagery. This equipment is a Honeywell Model 1856 fiber-optics/ CRT recorder with a film magazine that records intensity-modulated video data on photographic roll film. The recorder can also use light-developed oscillograph paper for quick-turnaround test and setup procedures. The equipment used in this effort consists of an Ampex SP300 ¼-inch tape recorder/ reproducer, a number of breadboard modules, a storage oscilloscope, and a strip film recorder.

Several breadboard processing models were built to provide mixing, filtering and level shifting. The data used for producing the images shown in the following section were collected during Mission 184. Wet-processed photosensitive

paper was the recording medium.

Exposure tests using a sinewave oscillator were conducted to determine recorder beam intensity and signal swing necessary for proper exposure and developing. These tests later proved to be of no value because of a dc component present on the tape-recorded.

Figures 19 and 20 are a direct playback of raw data from channels 1 and 2, respectively, of the Mission 184 data. The 3-5 μm data, Channel 1, show more contrast than do the 8-14 μm data channels. This is surprising, because the imagery was flown on a predawn mission. Part of the explanation is that the Channel 2 data were riding on a 0.5-volt offset. The background is washed out because of this offset. The geologic content of this imagery is minimal. By comparison, the 3-5 μm data show considerable detail in both structure and lithology.

Figure 21 shows the results of electronically mixing Channels 1 and 2. The principal effect of this processing was an increase in contrast and a resulting enhancement of cool targets. Hydrologic features appear more evident, along with an enhancement of the lithology having a lower thermal diffusivity.

Further testing was done using frequency filters. It was expected that improvement of imagery would result from using a low-pass filter (9 kHz) that would tend to remove small thermal features and enhance larger ones. Some degree of success was achieved, but the benefits do not justify continuation.

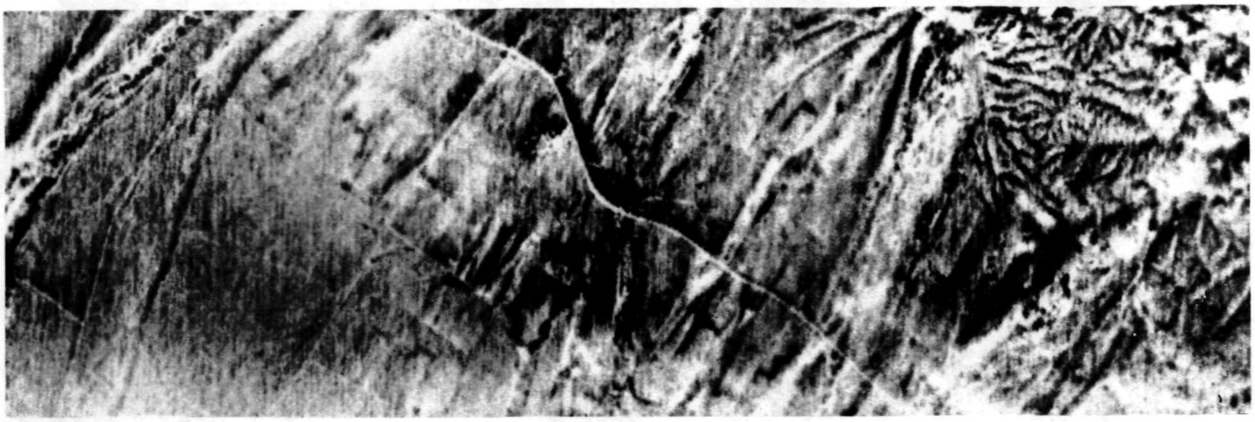


Figure 19. Raw scanner imagery, 3-5 μm.

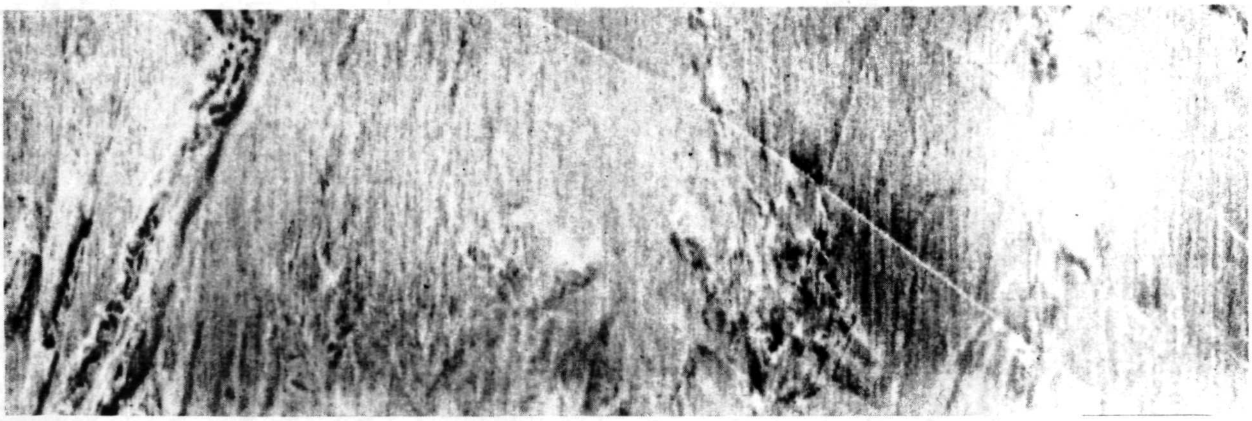


Figure 20. Raw scanner imagery, 8-14 μm.

Figure 21. Mixed video, additive.

Infrared Spectrometer Data Reduction

The initial effort toward the reduction of infrared (IR) spectrometer data began during the first year of the Bonanza Program. It was once thought that emission spectra obtained under laboratory conditions could be correlated with data gathered from aircraft. A significant amount of work was done collecting representative samples of rock types found in the Bonanza Test Site. Rock with both fresh, broken and weathered surfaces was processed through a parabolic reflectometer to obtain spectra. The result of this effort is discussed in the First Year Bonanza Summary Report (MCR-70-80).

During the second year, data from Mission 105 were received and computer processing began. The original approach was to search for a unique identifier that would be determinable from spectrometer output. This proved to be impractical and the emphasis was then directed toward a means to process spectral emission data rapidly and display it in a form that aids the interpreter.

It was decided to investigate whether relative differences in spectra could be used to discriminate one rock from another. Although the separation of spectra into categories would not be the ultimate answer, it would demonstrate that the information sought was, in fact, contained in emitted radiation. The data from Mission 105 lacked both adequate signal-to-noise ratio (S/N) and a water calibration, but the results of the processing were sufficiently encouraging to request another aircraft mission

on which the spectrometer would be flown.

These requests were made but problems with the instrument and/or unfavorable weather prevented the acquisition of additional data until Mission 184 was flown in September 1971. To further complicate the problem, the magnetic tape data request was inadvertently omitted from the original mission request. A supplementary data request was forwarded to MSC and the tape ultimately received.

Data from Mission 184 consisted of digital magnetic tape and plots from five flight lines. The format of the magnetic tapes was changed from those received during the second year of the program, requiring some additional programming not originally anticipated. The quality of the data on the computer tape was far superior to that from Mission 105 in that the S/N was factor 3-4 better. Also, the flight lines included water spectra, which are necessary for removing atmospheric and filter irregularities.

The boresight camera photography, however, does not have a data block and, hence, is not usable to verify the results of the programming. Without time correlation, there is no way that the spectrometer data can be correlated with the overflown terrain. In spite of this major problem, it was decided to proceed with the processing to determine if a recognizable pattern could be extracted from the data that would relate to probable changes in lithology.

If one desires to obtain radiometric accuracy from spectrometer data, the water calibration target would have to

be extensively instrumented to determine the temperature. Because this is not practical (or necessary) it is assumed that, in general, the water is reasonably uniform and not greatly divergent in temperature from the surrounding landscape.

It was assumed that water approximates a blackbody. Six clean water spectra were selected from the computer output plots supplied by NASA, and this information was put into the program to function as a prefilter. The water spectra were assumed to contain both the atmospheric variations and circular variable filter anomalies. Point-by-point subtraction of the water spectra from the unknowns (i.e., overflown terrain) was the next step, resulting in normalized spectral data, presumably with atmospheric and filter effects removed. The resulting normalized data were then filtered by a three-point moving-average routine to remove noise. After this preprocessing was completed, the spectra were operated upon to select all points of minima and maxima and those points were flagged with an asterisk. The resulting printout is rows of asterisks indicating compositional discontinuities in the overflown terrain. Computer programs have been written and data processed using the above described approach. The output consists of dot patterns and is interpreted as discussed below.

Line 64 was collected along a N-S line slightly to the west of the Bonanza caldera. Line 64 begins in an area overlain by clastic sediments derived mainly from volcanics, and traverses both sedimentary and igneous intrusive rock. Without boresight photography to tie a point on the ground to a particular spectrum, exact correlations cannot be made. Figure 22 shows a portion of

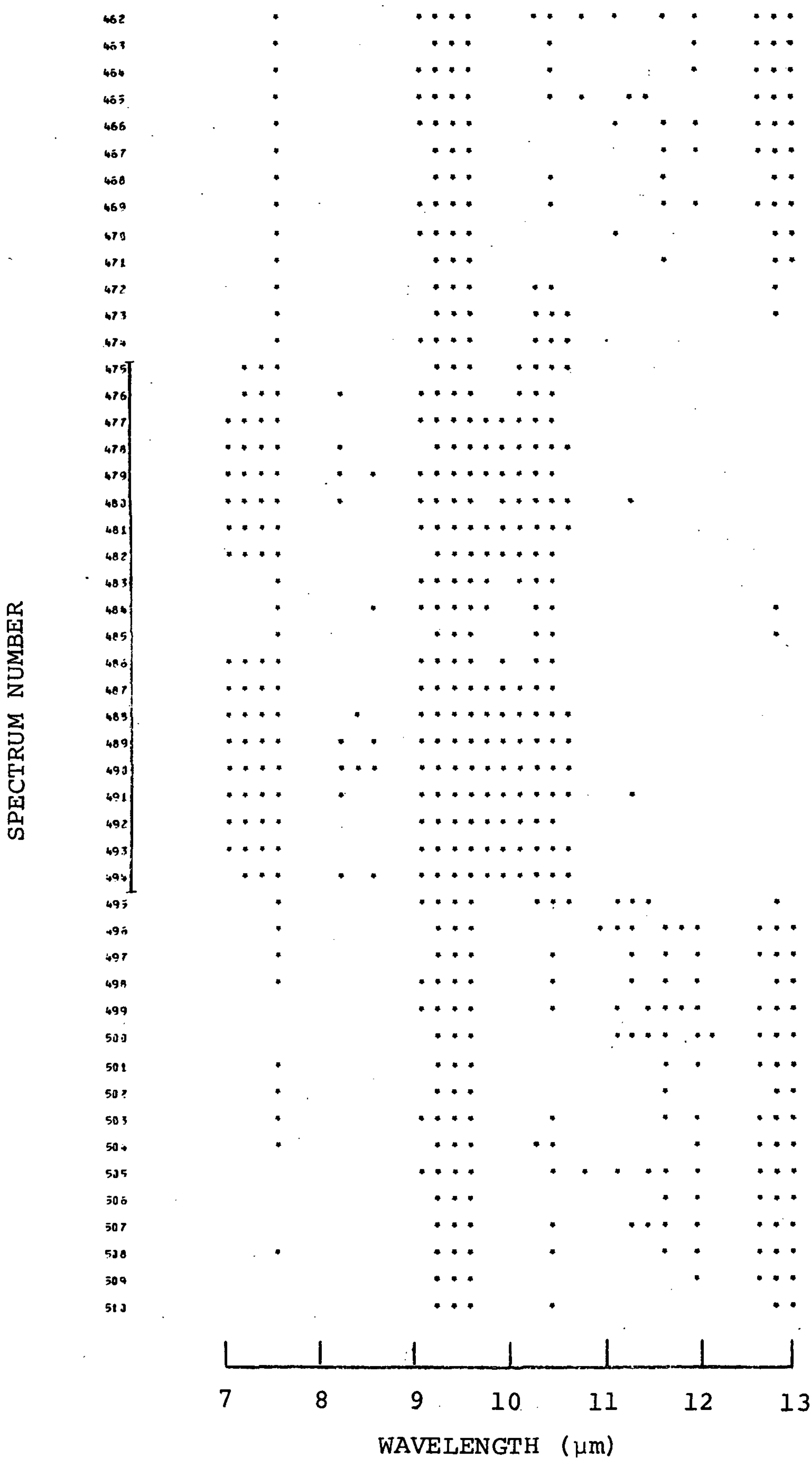


Figure 22. Typical computer printout of ARSS data showing distinctive Reststrahlen patterns.

the computer output that corresponds to approximately ½ mile of Line 64 near the midpoint. Within the portion shown, a distinct pattern emerges. The patterns shown in Spectra 475-494 appear to define a rock type different from those on either side. Further investigation is required to determine whether this is actually so. One conclusion is that the rock seen by the spectrometer at these points is high in silica and ferro-magnesian minerals because the absorption points are exclusively in the 7-10 μm region. Other spectra like those shown in 495-510 show a predominance of spectral structure in the 10-13 μm region. These minerals most likely are limestones, limey-shales or other carbonate rocks.

Obviously the technique and data presented here are in no way conclusive, but if one could remove the instrumental deficiencies and accommodate the effects contributed by the atmosphere, then an airborne IR spectrometer could emerge as one of the more powerful remote sensing tools.

Unfortunately, the instrument and data problems encountered by NASA preclude any definitive answers or evaluations. The discussion above demonstrates the potential discriminatory power of the IR spectrometer once again (as R.J.P. Lyon has shown in the past), but data problems prevent further verification. Without timed boresight photography, and with invalid time on the aircraft tape itself, it becomes impossible to identify a 40-foot ground spot in the Bonanza Mountains.

Plans

IR spectrometry has been requested for an upcoming mission in June 1973. We will try again.

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PERSONNEL CHANGES

Faculty

Daniel H. Knepper	Research Faculty, from 15 January 1973
Keenan Lee	Assoc. Principal Investigator, until 15 January 1973
	Principal Investigator, from 15 January 1973
Robert G. Reeves	Principal Investigator, until 15 January 1973
David W. Trexler	Research Faculty, from 15 January 1973

Research Associate

Don L. Sawatzky	From 15 January 1973 until 31 March 1973

Research Assistants

James C. Fisher	From 15 January 1973
Daniel H. Knepper	Until 15 January 1973

Secretarial

June Lofts	Until 10 October 1972
Kitty J. Huntley	From 16 October 1972

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